The Electricity Supply Wedge:

A Strategic Plan to Reduce the Carbon Dioxide Intensity of Power Generation in the United States

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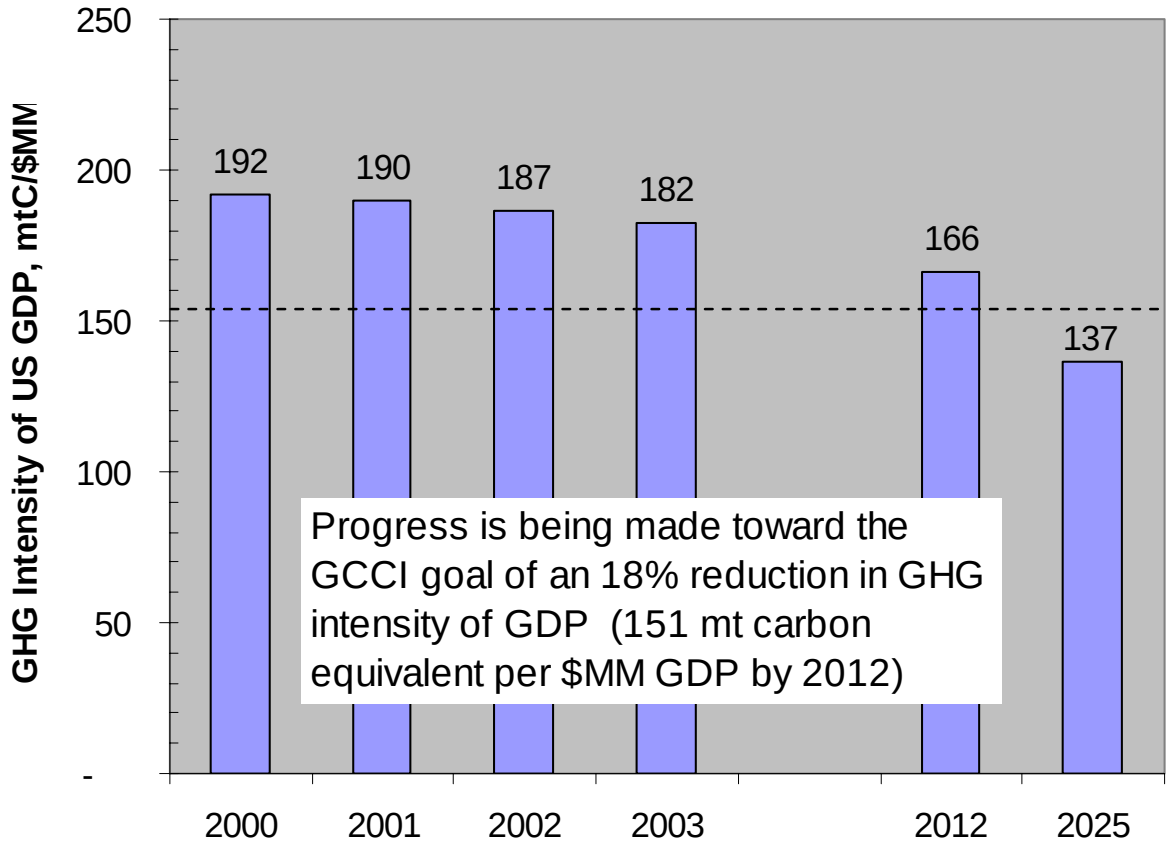
U.S. Global Climate Change Initiative (GCCI)



Information Sources: EIA AEO 2005, EIA Emissions of Greenhouse Gases in the United States 2003, CarBen Model for projections of non-CO2 GHG emisions.

U.S. CO_2 REFERENCE CASE, 2001 - 2025:

Improvements in U.S. GHG intensity are overwhelmed by population and economic growth.
Annual U.S. GHG emissions increase by nearly 1 GtC/yr by 2025 (46% increase over 2001 level).

	2001	2012	2025
U.S. Population (millions over 16)	222	249	277
GDP per capita (thousand $/person)	45	56	73
GHG Intensity (tCeq/MM$)	190	166	137
Total GHG emissions ($MMmtC_{eq}$/yr)*	1,922	2,300	2,800

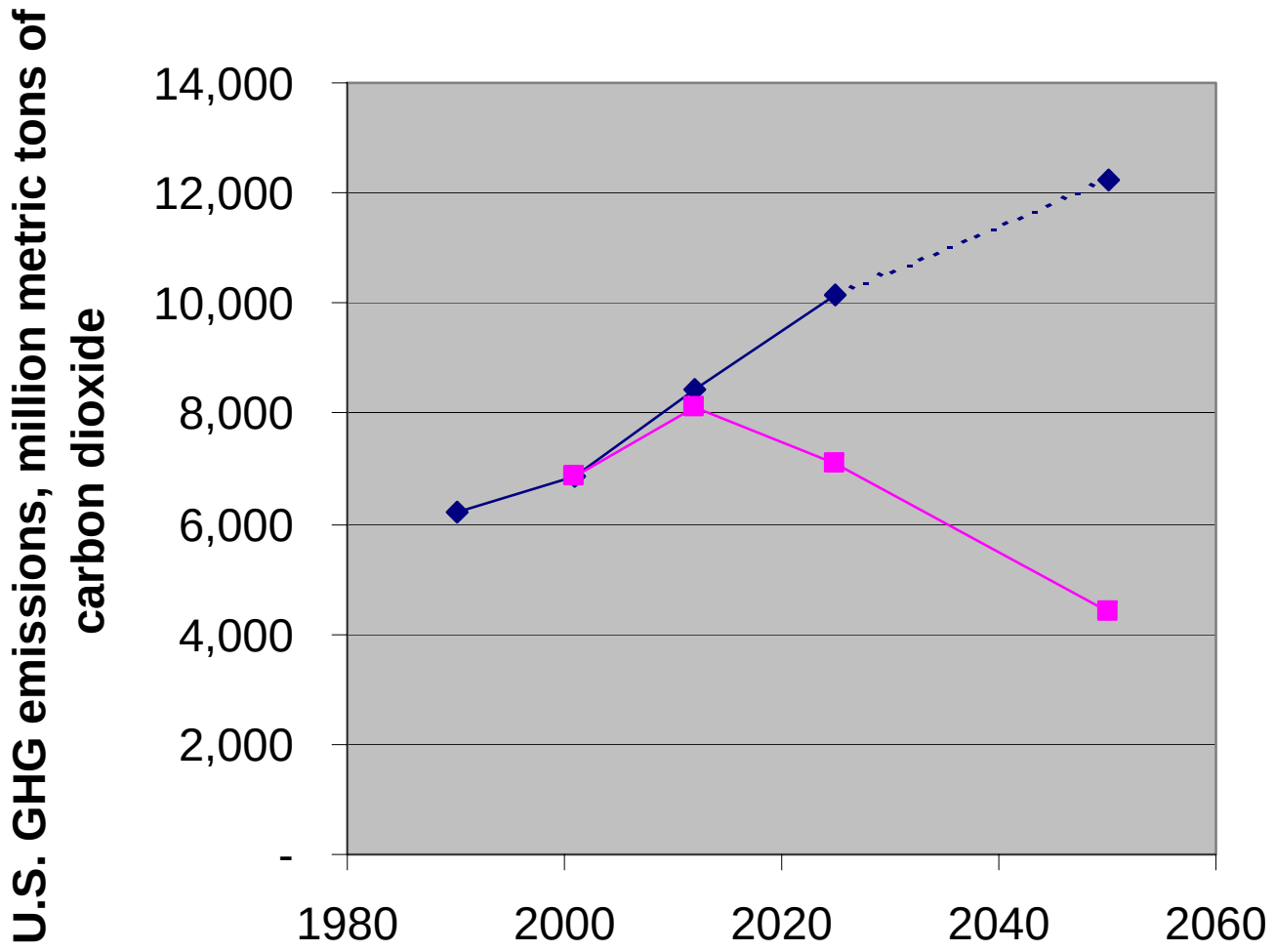
** Note: MMmtc is million metric tons carbon; GtC is billion metric tons carbon*

U.S. ELECTRICITY SUPPLY REFERENCE CASE, 2001-2025:

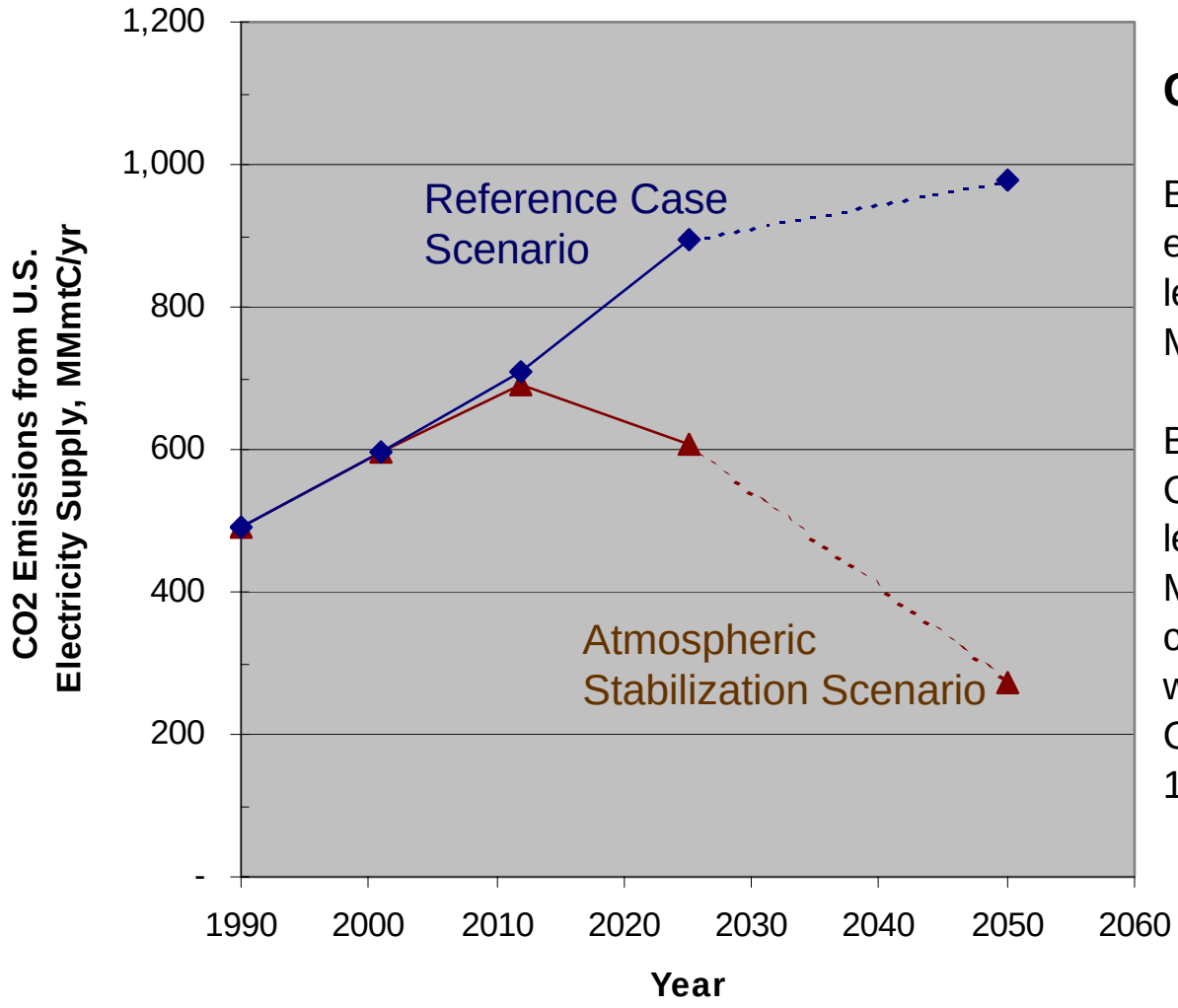
The CO_2 intensity of electricity supply is only 6% below the 2001 level through 2025.

	2001	2012	2025
Total Generation, BkWh	3,589	4,675	5,770
Percent of Generation from coal	52.5%	48%	50%
Avg. CO_2 Intensity of Elec. Supply (tC/MM$)	0.167	0.157	0.157
Sector GHG emissions ($MMmtC_{eq}$/yr)	597	734	904

U.S. Emissions of GHGs under the Reference and Atmospheric Stabilization Scenarios



ATMOSPHERIC STABILIZATION SCENARIO FOR U.S. ELECTRICITY SUPPLY

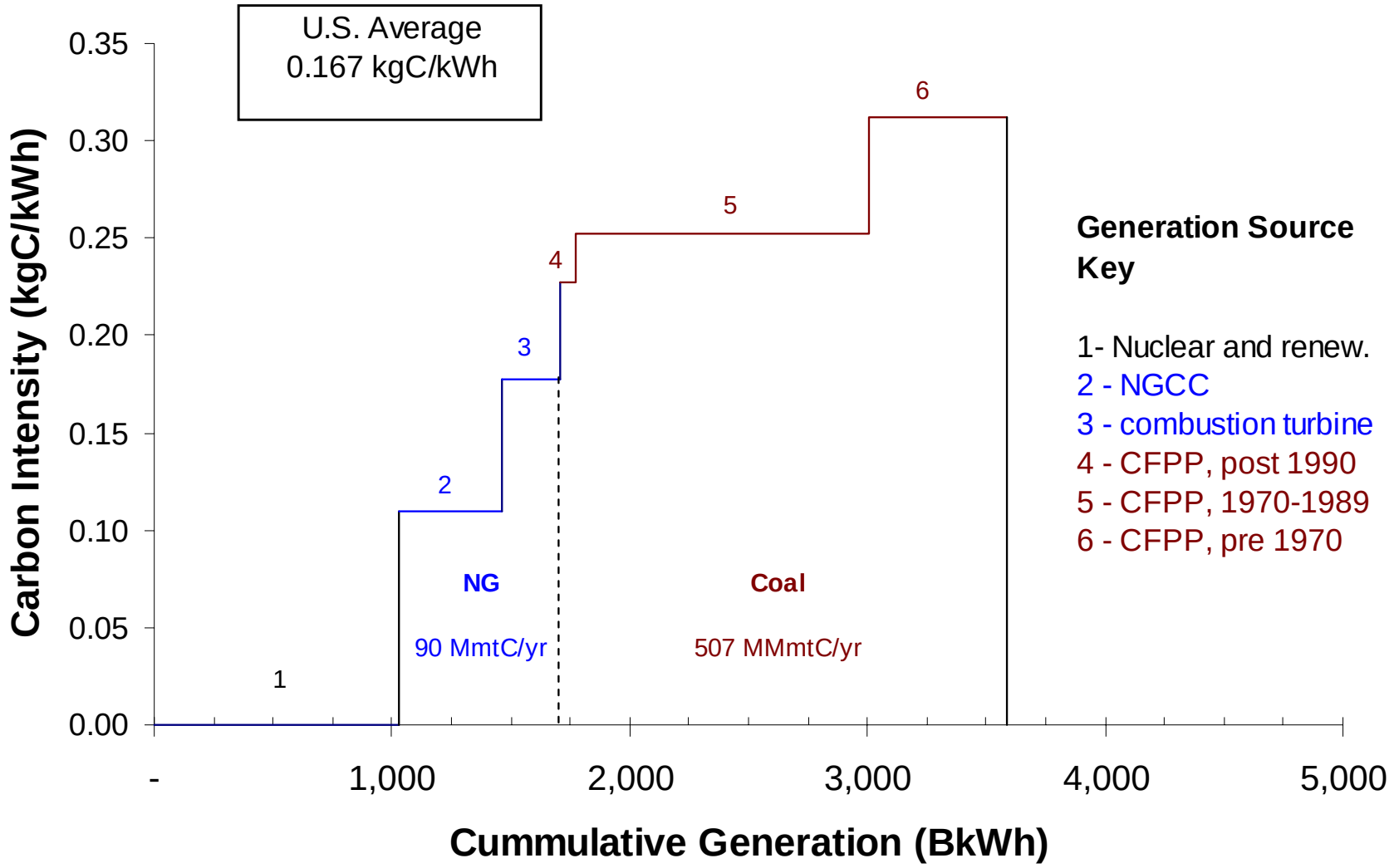


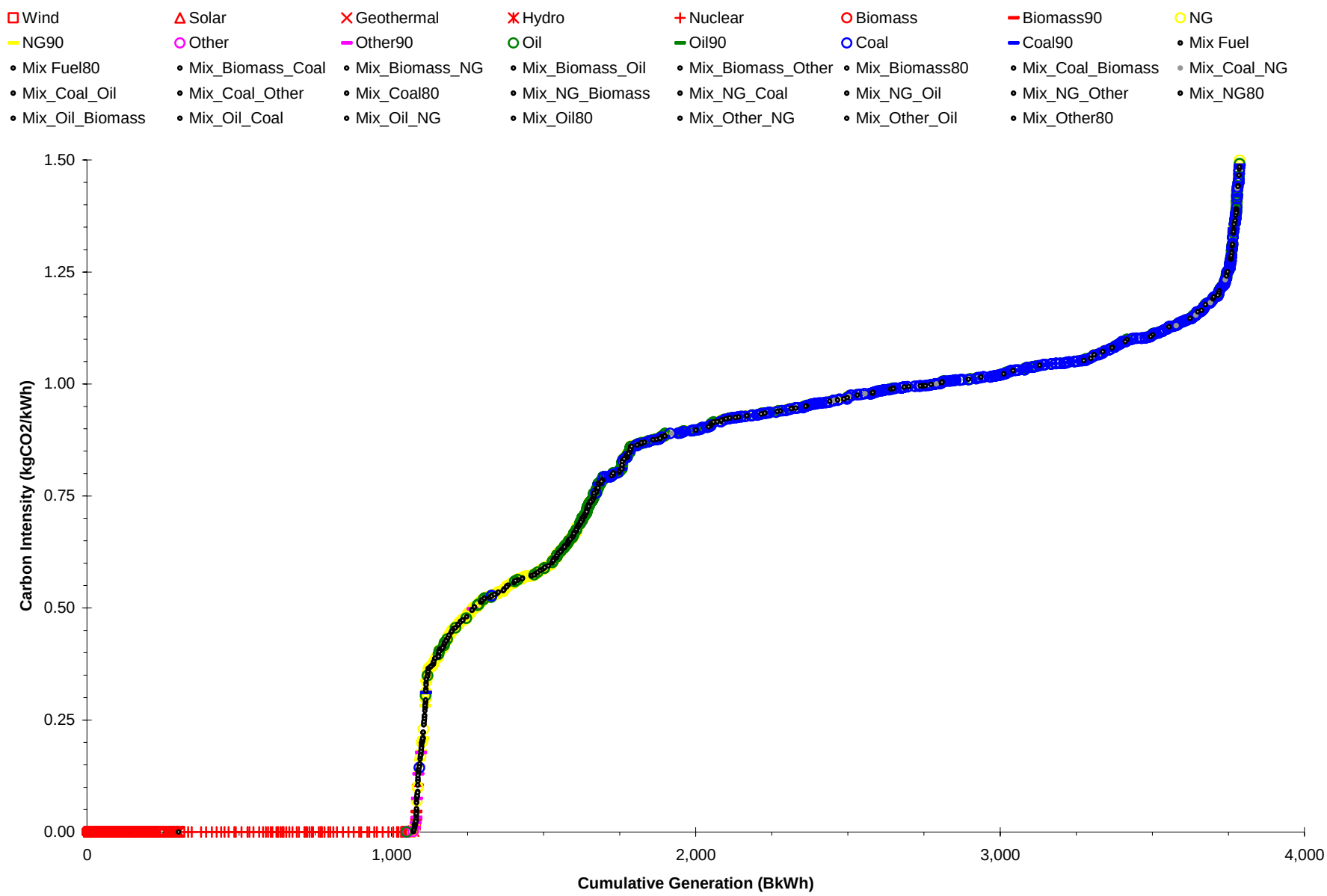
Goals:

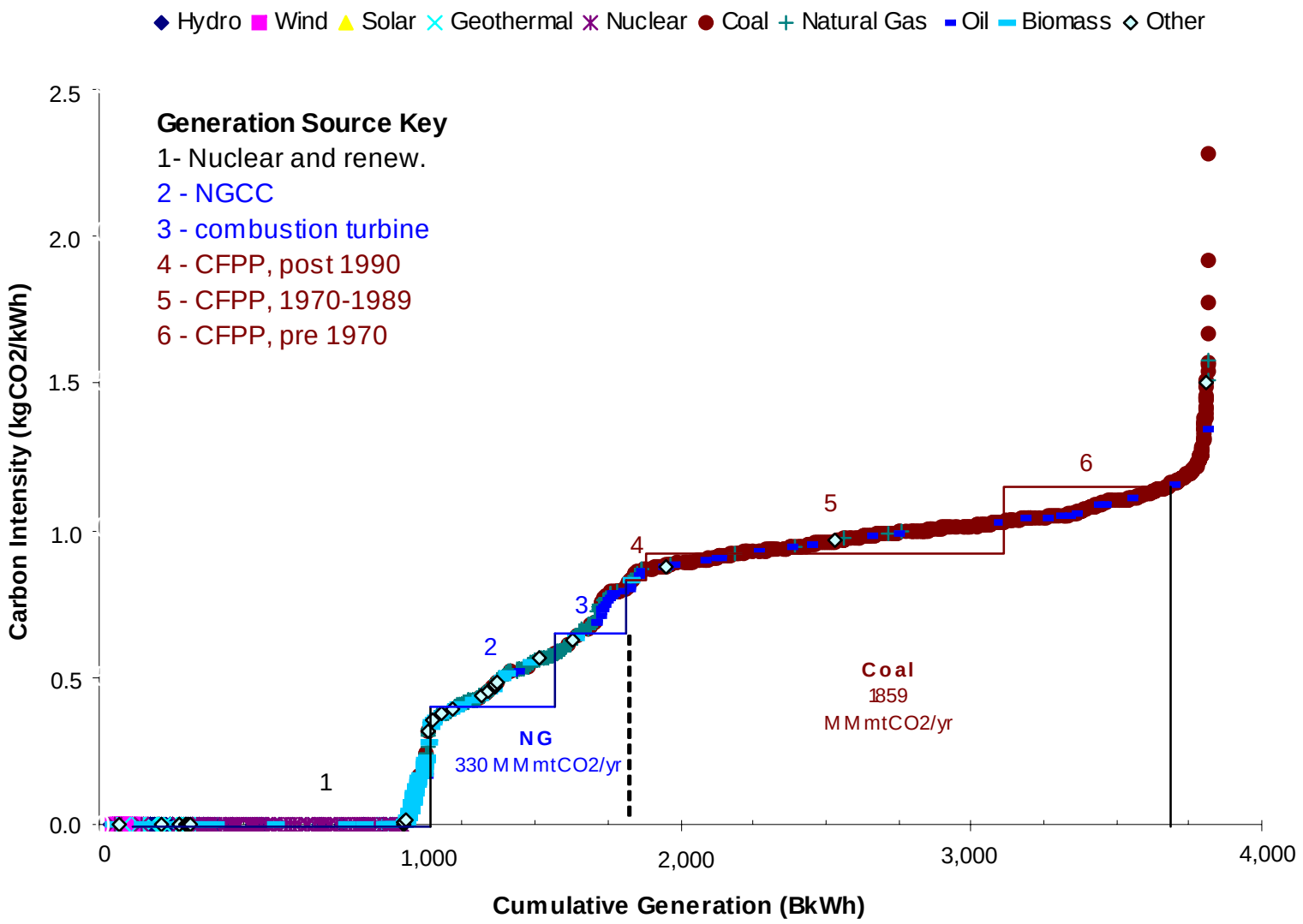
By 2025, stabilize emissions at 2001 level, 600 MMmtC/yr

By 2050, reduce CO2 emissions to less than 300 MMmtC/yr, commensurate with economy-wide GHG target of 1,200 MMmtC/yr

MARGINAL CARBON INTENSITY CURVE FOR U.S. ELECTRICITY SUPPLY, 2001

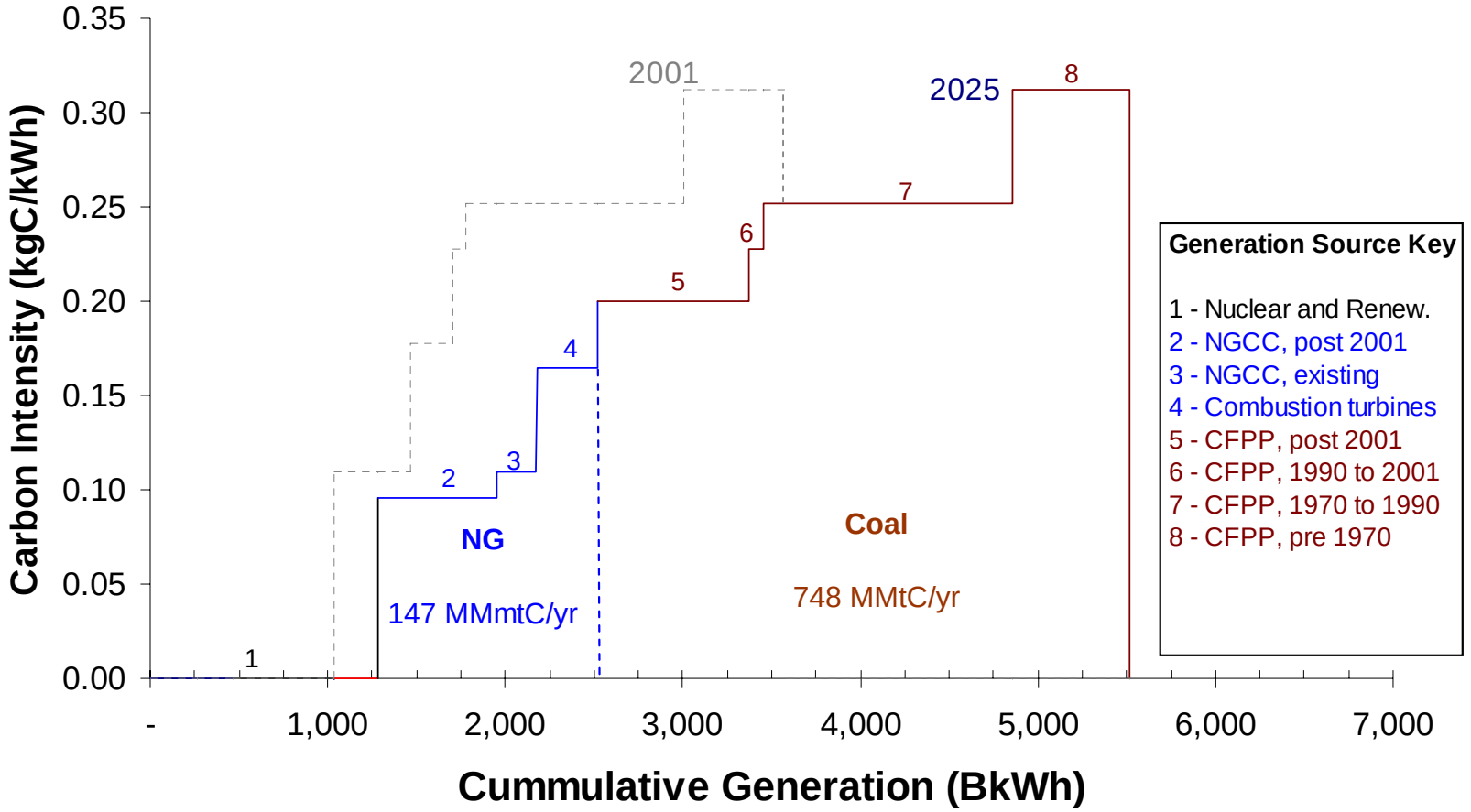



Wind
Solar
Geothermal
Hydro
Nuclear
Biomass
Biomass90
NG
NG90
Other
Other90
Oil
Oil90
Coal
Coal90
Mix Fuel
Mix Fuel80
Mix_Biomass_Coal
Mix_Biomass_NG
Mix_Biomass_Oil
Mix_Biomass_Other
Mix_Biomass80
Mix_Coal_Biomass
Mix_Coal_NG
Mix_Coal_Oil
Mix_Coal_Other
Mix_Coal80
Mix_NG_Biomass
Mix_NG_Coal
Mix_NG_Oil
Mix_NG_Other
Mix_NG80
Mix_Oil_Biomass
Mix_Oil_Coal
Mix_Oil_NG
Mix_Oil80
Mix_Other_NG
Mix_Other_Oil
Mix_Other80
Carbon Intensity (kgCO2/kWh)
1.50
1.25
1.00
0.75
0.50
0.25
0.00
0
1,000
2,000
3,000
4,000
Cumulative Generation (BkWh)


Hydro
Wind
Solar
Geothermal
Nuclear
Coal
Natural Gas
Oil
Biomass
Other
Generation Source Key
1- Nuclear and renew.
2 - NGCC
3 - combustion turbine
4 - CFPP, post 1990
5 - CFPP, 1970-1989
6 - CFPP, pre 1970
Carbon Intensity (kgCO2/kWh)
2.5
2.0
1.5
1.0
0.5
0.0
0
1,000
2,000
3,000
4,000
Cumulative Generation (BkWh)
1
2
3
4
5
6
NG
330 MMmtCO2/yr
Coal
1859
MMmtCO2/yr

MARGINAL CARBON INTENSITY CURVE FOR U.S. ELECTRICITY SUPPLY, 2025 REFERENCE CASE

Coal provides about one-half of electric power and about 85% of emissions, in 2001 and 2025.



ASSUMED ECONOMIC RATIONALE FOR PURSUING GHG EMISSIONS REDUCTION OPTIONS

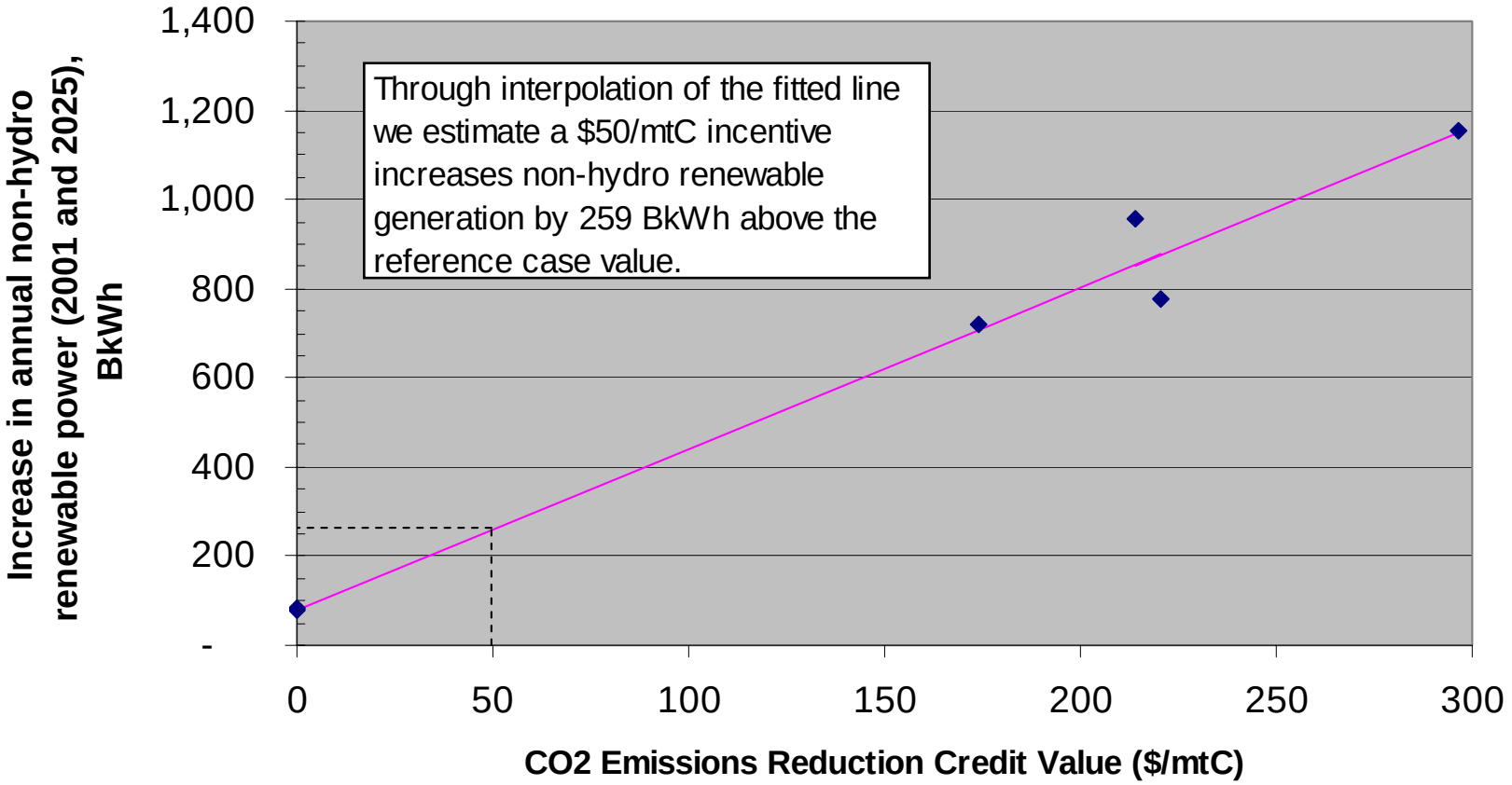
- **Emissions reduction credit of $10 per mtC in 2012, increasing $50 per mtC in 2025**
  - **Consistent with values applied in the overall benefits analysis**
  - **Equivalent to $3 per ton CO_2 in 2012 and $14 per ton CO_2 in 2025**
  - **Adds about $0.01 per kWh for power generation**

OPTIONS FOR REDUCING GHG EMISSIONS FROM U.S. ELECTRICITY SUPPLY SECTOR, ATMOSPHERIC STABILIZATION SCENARIO

- **Increased deployment of non-hydro renewables**
- **Reduced demand for electricity per unit of GDP**
- **Accelerated capital stock turnover**
- **Increased efficiency of new coal and natural gas fired power plants**
- **Carbon dioxide capture and storage**

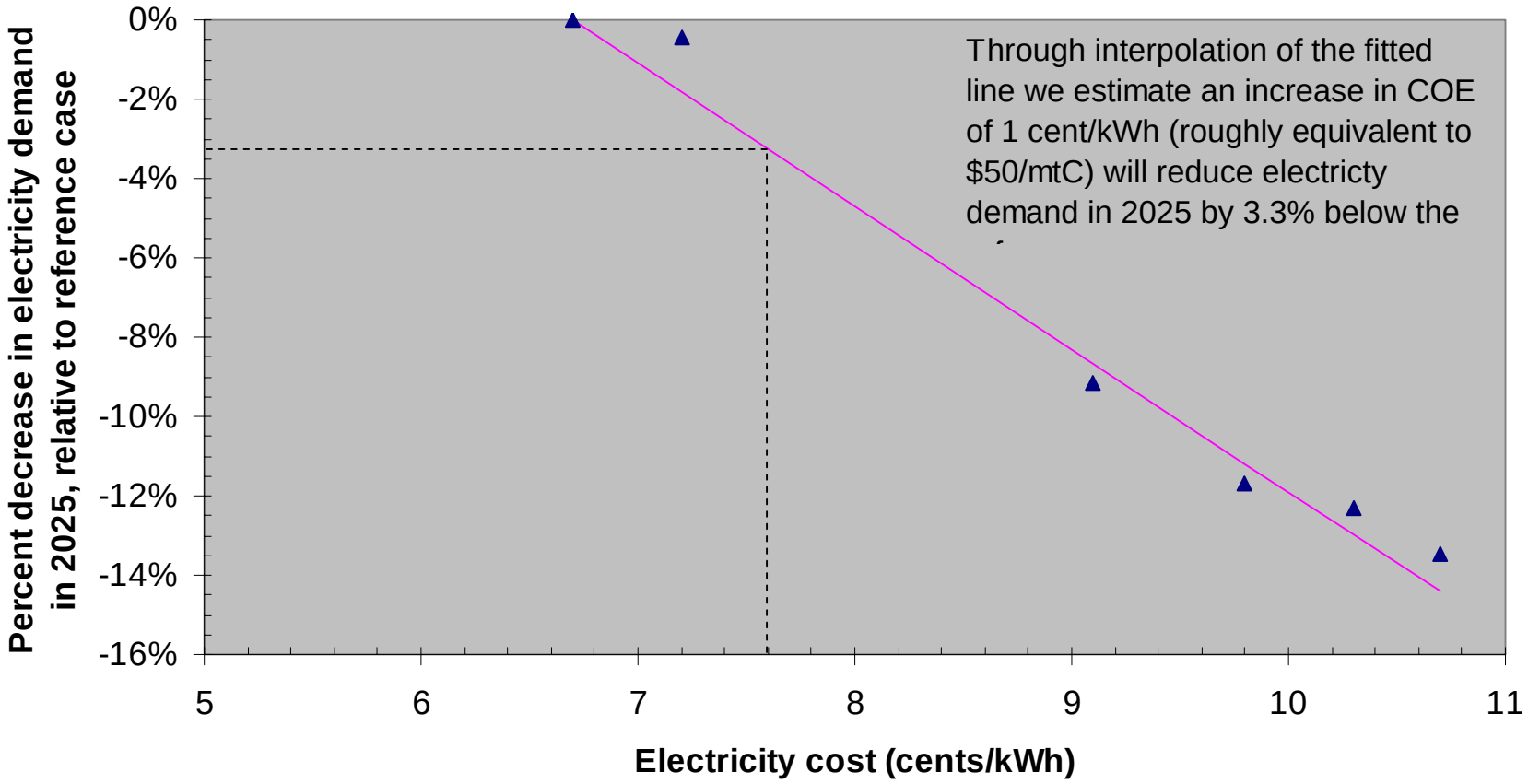
Terrestrial offsets and off-grid renewables/CHP are applied elsewhere in the economy-wide benefits analysis

NON-HYDRO RENEWABLES



From EIA's assessment of S.139, June 2003

ELECTRICITY DEMAND



From EIA's assessment of S.139, June 2003

POWER PLANT EFFICIENCY

Technology progress and carbon credits lead to higher efficiencies for new coal-fired power plants

Average efficiency of new coal-fired power plants (HHV)		
	Reference Case Scenario	Atmospheric Stabilization
2002-2012	40.5%	42.7% [1]
2013-2025	47.4% [2]	56% [3]

[1] EIA analysis of S.139, advanced coal reference case, 2002

[2] EIA analysis of S.139, advanced coal reference case, 2002

[3] High range of CURC roadmap (50-60%) adjusted down to account for earlier deployments

ACCELERATED CAPITAL STOCK TURNOVER

(GW of existing coal-fired power plant capacity in service)

Coal-fired power plant vintage	2001	2025 Reference Case	2025 Atmospheric Stabilization
Pre-1970 (0.31 kgC/kWh)	109	98.1	0
1970-1989 (0.25 kgC/kWh)	188	188	187
1990-2001 (0.23 kgC/kWh)	11	11	11

MODEL OF U.S. COAL-FIRED GENERATION, 2001 REFERENCE CASE

Power Plant Vintage	Capacity (GW)	Capacity Factor	Generation (BkWh)	Average Efficiency (HHV)	Coal Used (Qbtu)	Carbon Intensity* (kgC/kWh)	Total CO_2 Emissions (MMtc)
pre-1970	109	61%	580	28.4%	7.0	0.31	181
1970-89	188	75%	1,230	35.2%	12.0	0.25	310
1990-01	11	75%	72	39.0%	0.6	0.23	16
Total	*307*	*70%*	*1,882*	*33%*	*19.5*	*0.27*	***507***

Coal-fired capacity by vintage from EIA questionnaire data
Capacity factor estimated by authors to align capacity, generation, and coal use reported in AEO 2004
*Coal emissions factor 25.98 MMmtC/QBtu, EIA Emissions of GHGs in the U.S., 2001, table B1

MODEL OF U.S. COAL-FIRED GENERATION, 2025 REFERENCE CASE

Power Plant Vintage	Capacity (GW)	Capacity Factor	Generation (BkWh)	Average Efficiency (HHV)	Coal Used (Qbtu)	Carbon Intensity* (kgC/kWh)	Total CO_2 Emissions (MMtc)
pre-1970	98	78%	666	28.4%	8.0	0.31	208
1970-89	188	85%	1,396	35.2%	13.5	0.25	352
1990-01	11	85%	82	39.0%	0.7	0.23	19
2002-2012	*46*	*85%*	*342*	*40.5%*	*2.9*	*0.22*	*75*
2013-2025	*66*	*89%*	*510*	*47.4%*	*3.7*	*0.19*	*95*
Total	*408*	*84%*	*2,996*	*35.5%*	*28.8*	*0.25*	***748***

Coal-fired capacity by vintage from EIA questionnaire data
Capacity factor estimated by authors to align capacity, generation, and coal use reported in AEO 2004
*Coal emissions factor 25.98 MMmtC/QBtu, EIA Emissions of GHGs in the U.S., 2001, table B1

ECONOMICS OF CO_2 CAPTURE AND STORAGE

Lower-cost CO_2 capture technology and sequestration incentives provide a "cost-effective" pathway for the power sector.

PC Boiler (w/coal)*	$0.043/kwh
Gasification (w/pet coke and CO_2 recovery)*	$0.064/kwh
• Technology Progress (50% cost reduction for CO_2 capture)**	($0.011/kwh)
• CO_2 Sequestration Incentive (@ $50/mtC)	($0.010/kwh)
Net Costs	$0.043/kwh

**Based on SFA Pacific and IEA GHG cost models.*
***Based on CCP goals of 60% cost reduction for CO_2 capture technology.*

CARBON SEQUESTRATION

Reference Case: CO_2 capture and sequestration not deployed.

Atmospheric Stabilization: Small use by 2012, considerable deployment during 2013-2025.

		Percent of new plants w/seq	GW of new plants w/seq	Parasitic load from CO_2 capture	Carbon Intensity, kgC/kWh
Coal	2002-2012	4.2%	2.1	15%	0.024
	2013-2025	75%	79.4	12%	0.018
Natural gas	2002-2012	3.4%	2.0	20%	0.012
	2013-2025	50%	40.4	14%	0.010

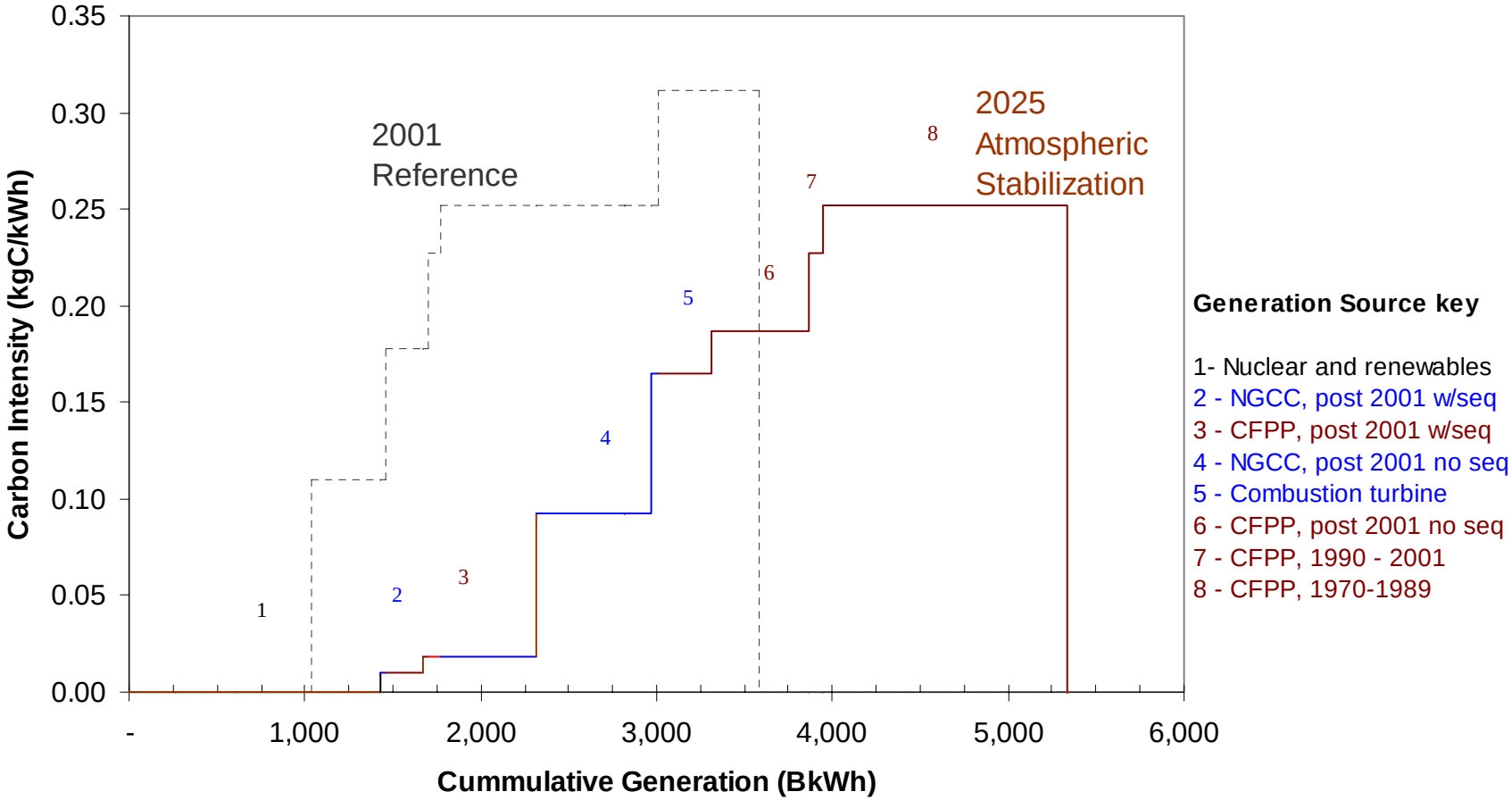
OVERVIEW OF EFFICIENCY, STOCK TURN-OVER, AND SEQUESTRATION, COAL POWER IN 2025

		Reference Case Scenario			Atmospheric Stabilization Scenario		
Coal-fired power plant vintage		Capacity (GW)	Average efficiency* (HHV)	Total CO_2 emissions (MMtc)	Capacity (GW)	Average efficiency* (HHV)	Total CO_2 emissions (MMtc)
Pre-1969		98.1	28.4%	208	0	28.4%	0
1970-89		187.5	35.2%	352	187.0	35.2%	351
1990-01		11.0	39.0%	19	11.0	39.0%	19
2002-2012	(w/out seq)	45.9	40.5%	75	39.8	42.7%	65
	(w/seq)	0		0	2.1	38.8%	0
2013-2025	(w/out seq)	65.8	47.4%	95	30.0	55.8%	38
	(w/ seq)	0.0		0	79.4	49.1%	11
Total		*410.6*	*35%*	***748***	*365.9*	*40%*	***484***

* Efficiency estimates taken from EIA's analysis of S.139. 47.4% is the high tech 2002 technology n^{th} plant performance. Stabilization scenario efficiencies are adjusted upwards based on goals contained in the 2003 CURC roadmap. The efficiency of the "with sequestration" plants are reduced based on an estimated parasitic load of 15% in 2012 and 12% in 2025, consistent with progress toward NETL program goals.

PATHWAY TO STABILIZATION

The areas under the two curves are equal - GHG emissions stabilized
Avg. GHG Intensity of Electricity supply reduced from 0.167 to 0.114 kgCkWh, nearly 43% of generation essentially carbon emission free.

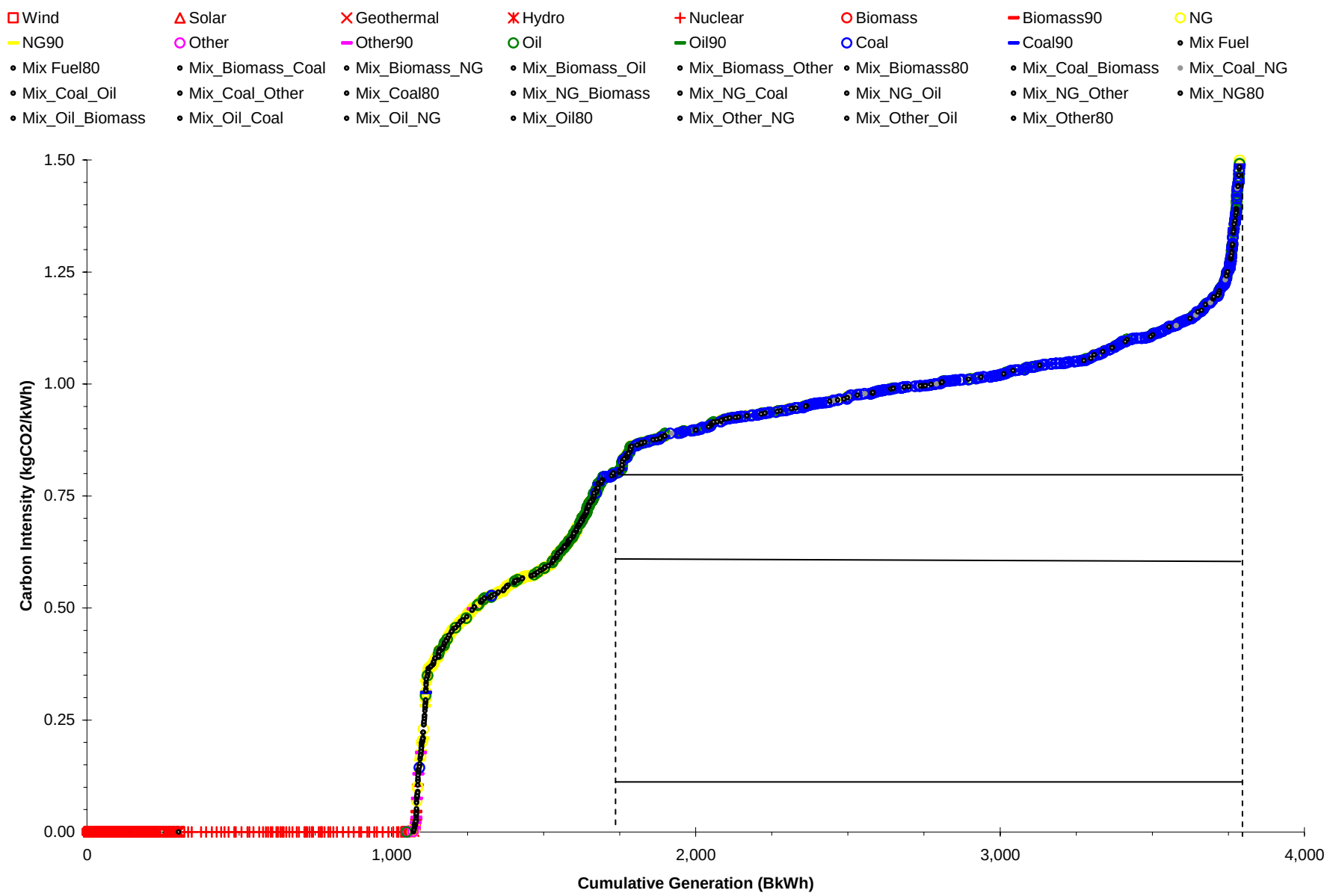


U.S. ELECTRICITY SECTOR GHG EMISSIONS WEDGE

Emissions Reductions Contributions Relative to Reference Case (MMmtC/yr)

Integrated scenario provides 290 MMmtC/yr reduction, enabling power sector to achieve goal, even though generation is up to 50%.

Option	2025
Increased Renewables	28
Reduced Demand	34
Capital Stock Turnover	83
Improved Efficiency	34
Coal Power Plants w/ seq	93
NG Power Plants w/seq	18
Total	**290**


Wind
Solar
Geothermal
Hydro
Nuclear
Biomass
Biomass90
NG
NG90
Other
Other90
Oil
Oil90
Coal
Coal90
Mix Fuel
Mix Fuel80
Mix_Biomass_Coal
Mix_Biomass_NG
Mix_Biomass_Oil
Mix_Biomass_Other
Mix_Biomass80
Mix_Coal_Biomass
Mix_Coal_NG
Mix_Coal_Oil
Mix_Coal_Other
Mix_Coal80
Mix_NG_Biomass
Mix_NG_Coal
Mix_NG_Oil
Mix_NG_Other
Mix_NG80
Mix_Oil_Biomass
Mix_Oil_Coal
Mix_Oil_NG
Mix_Oil80
Mix_Other_NG
Mix_Other_Oil
Mix_Other80
1.50
1.25
1.00
0.75
0.50
0.25
0.00
Carbon Intensity (kgCO2/kWh)
0
1,000
2,000
3,000
4,000
Cumulative Generation (BkWh)

CONCLUSIONS

- With carbon sequestration technology combined with efficiency and renewable energy systems, and working within normal capital stock turnover, it is possible to stabilize power sector emissions at the 2001 level by 2025.
- A framework and draft model based on marginal CO_2 intensity is presented for evaluating different CO_2 emissions mitigation options.

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